The Specialist Committee on Stability in Waves

Committee Chairman: Dr. Jan-Otto de Kat
Session Chairman: Dr. Naoji Toki

1. DISCUSSIONS

1.1 Comments to the 24th ITTC Specialist Committee on Stability in Waves by Bruce Johnson, U.S. Naval Academy, USA

I congratulate the Specialist Committee on their comprehensive Report on the state of the art in predicting stability in waves, a subject of great interest to all sea going individuals, including the Princess Royal, who addressed safety issues in her remarks to the 24th ITTC.

1. Since the Committee concluded that "No code has reproduced consistently all required simulation scenarios with satisfactory conformance to the experimental data" (p.377) I suggest that we abandon the term "Capsize Index" and develop a "Survivability Index" instead. I doubt that any code or limited set of experiments will adequately predict anything other than a roll induced capsize in specific wave conditions. We are far from numerically predicting capsizes in breaking wave conditions. However, a Survivability Index could form the basis for operator guidance concerning situations which could lead to dangerous ship motions such as parametric roll, and which could lead to possible capsizes, if one is unlucky enough to be in the wrong place at the wrong time.
2. Sections 2.2 and 2.3 and other experimental investigations confirm that the worst case stability situation is **not** "perched on a wave whose length equals to the ship length". The Committee needs to take a stand on this erroneous assumption which continues to be used by naval architects and regulators alike. John Womack and I have addressed this issue in our upcoming SNAME paper "A Systematic Study of Wave Phasing on Righting Arm Curves for Fishing Vessels" paper D-15 at the Houston meeting October 20th, 2005.
3. I was disappointed that with all the good data available for fishing vessel A-2 including high steepness wave tests, the Committee chose to limit the comparisons to wave steepness of 1/15 and lower. Figure 1.1 in Womack and Johnson (2005) demonstrates that the dramatic reductions in righting arm (GZ) curves mostly take place at steepnesses greater than 1/15. The ability of numerical analysis programs to handle steep waves is limited, as is mentioned in the Report. However, safety at sea should be the primary concern of at least one ITTC Committee, with validation of various CFD programs as one of their tasks. The damage done to the 20 missing offshore platforms during Hurricane Katrina comes to mind. They all must have passed some kind of IMO/USCG "one size fits all" criterion and still did not survive the hurricane. It is time to look seriously at performance based stability criteria based on solid model and full-scale

tests, rather than political compromise. I thought that is what towing tanks are for!

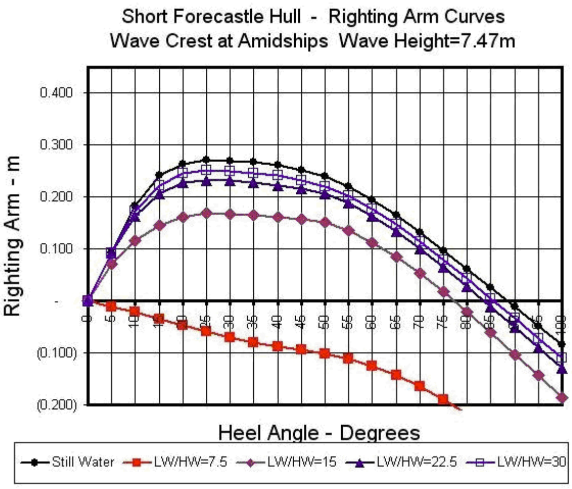

Figure 1.1- Righting arm curves (Womack and Johnson, 2005).

4. Although the stated references may contain GZ curves for the model tests, only listing the GM for vessel A-2 on page 373 is an inadequate description of the vessel's overall stability.
5. In Section 3 on damaged stability, the flooding process is discussed on page 386. You mention that the basic Bernoulli equation modified by semi-empirical weir coefficients proved to be satisfactory for the modelling of the water ingress/egress through a damage opening as well as for the flow between ship compartments. Our experience in attempting to calculate a time to flood analysis for the Arctic Rose using quasi-equilibrium time stepping and most of the assumptions discussed on page 386 demonstrated that the solutions tended to diverge as the number of flooding compartments increased beyond 3-4 (Johnson and Borlase, 2003). Could the Committee address this issue and how to deal with multiple degree of freedom flooding scenarios, before the IMO gets serious about time to flood analysis?

<u>References.</u>

Johnson, B. and Borlase, G., 2003, "Time to Flood Analysis for the Fishing Vessel Arctic Rose", <u>Proc. of the SNAME WMTC Conference</u>, San Francisco, USA.

Womack, J. and Johnson, B., 2005, "A Systematic Study of Wave Phasing on Righting Arm Curves for Fishing Vessels", <u>2005 SNAME Maritime Technology Conference</u>, 19-21 October, Houston, USA.

1.2 Contribution to the 24th ITTC Specialist Committee on Stability in Waves by Marcelo Neves, LabOceano, COPPE/UFRJ, Brazil

With regard to parametric resonance in head waves, it is accepted that for many ship designs the simulation models available are capable of reproducing with confidence the roll amplifications resulting from parametric resonance. But, unfortunately, there are some known cases in which the numerical models tend to over-predict the resonant rolling motions observed in experiments, as pointed out by some authors. These strong amplifications are associated with specific values of metacentric height, ship speed and stern shape (and, in general, other design parameters) in steep waves. In these cases, the classical Mathieu type modelling, in which parametric excitation is assessed considering terms up to the second order, tends to predict excessive excitation. Our attempts to reproduce the strong amplifications observed in the head sea tests with a transom stern hull of a typical 21m fishing vessel employing a second-order non-linear mathematical model also indicated excessive amplifications in the simulations.

In order to understand parametric resonance it is important to realize that it is essentially a resonant process and as such, very much dependent on the shape of the potential energy governing the process. The coupling of the three restoring modes, the heave and pitch modes with the roll motion is essential, and under conditions conducive to parametric amplification these vertical motions tend to be intense and asymmetric. Non-linear Froude-Krylov (2nd and 3rd order) force and moments will also play an important role in the specification of the potential energy.

In order to cope with the complex coupling of the three restoring modes, we have proposed an extended mathematical model with coupling terms defined up to the third order. Mathematically coupled models are commonly employed in manoeuvring studies by means of the so-called *derivative* model. A *derivative* model may as well be derived in order to describe the effects of couplings in waves. Such a model will give efficient numerical integration of the non-linear system of equations and a strong and qualified basis for the understanding of the complex dynamics behind the process of parametric amplification and the functional connections of the non-linear responses with hull form characteristics of interest to the ship designer. That may be achieved through judicious use of a highly non-linear model and well known analytical tools.

In particular, a stability analysis of the 3rd order non-linear model will display some characteristics not encountered in less comprehensive models, like the appearance of a hardening effect (due to coupling) proportional to wave amplitude squared, limiting the amplifications of a set of Hill's equation. In fact, the roll linear variational equation of an undamped (to simplify arguments) system will be in the form:

$$\left(J_{xx}+K_{\ddot{\phi}}\right)\ddot{\phi}+\left[K_{\phi}+R_0+R_1 Cos\left(\omega_e t+\tau_1\right)+ R_2 Cos\left(2\omega_e t+\tau_2\right)\right]\phi=0$$

where,
R_0 is the hardening term proportional to wave amplitude squared and dependent on 3rd order derivative terms,
R_1 is the amplitude of the harmonic amplification proportional to wave amplitude,
R_2 is the amplitude of the bi-harmonic amplification, proportional to wave amplitude squared.

For a mathematical model like the one given above the limits of stability may be plotted in a revealing way, see Figs. 1.2 and 1.3.

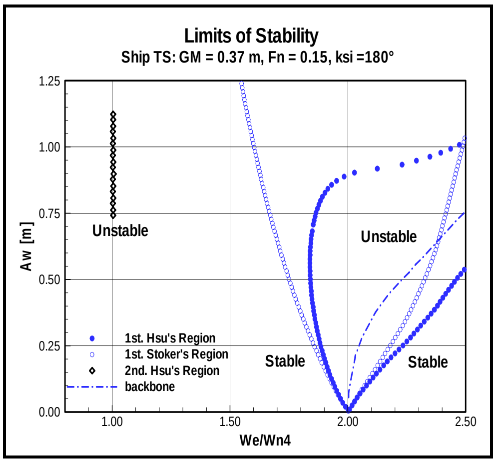

Figure 1.2- Limits of stability without damping: 2nd order versus 3rd order.

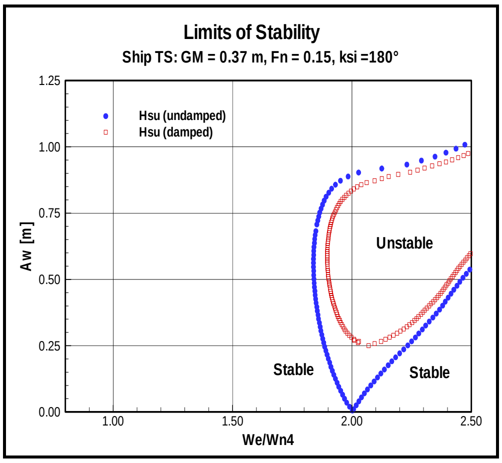

Figure 1.3- Limits of stability with damping.

It is seen that the new limits of stability bend to the right, whereas the classical Mathieu limits have a vertical backbone. This relevant aspect has not been considered in the literature, where usually only the non-linearities of the roll-roll curve are taken into account. These may assume the form of 3rd, 5th or even 7th order polynomials. The folding of the response curves characteristic of a Duffing equation, revealing the existence of a backbone curve is a well known dynamical characteristic.

Yet, in a third order coupled model it is possible to derive analytically the existence of the backbone curve associated with couplings of roll with vertical modes. This backbone curve is inclined to the right (hardening effect), as may be observed in Figs. 1.2 and 1.3, whereas the characteristic Duffing backbone curve for typical ships tends to be inclined to the left.

It should be observed that the final combination of the two backbone curves with distinct trends will determine in which conditions the coupled dynamic process will tend to display a more characteristic dependence on initial conditions and jump effect, due to couplings, and not to the roll-roll non-linearities of the restoring curve. In fact, the dependence of parametric amplification on initial conditions is an issue that requires attention. At the moment, it still remains as an open question, to which the Committee should devote great attention.

This contribution is finalised by stressing the urgent need for the establishment of a benchmark program on head seas parametric resonance, contemplating some peculiar hulls.

2. COMMITTEE REPLIES

2.1 Reply of the 24th ITTC Specialist Committee on Stability in Waves to Bruce Johnson

1. We agree that a capsize index is not sufficient to describe the degree of survivability. A “Survivability Index” might be more suitable, but a clear definition of survivability would be necessary. An alternative option is to express survivability in terms of the probability of not exceeding a critical value of one or more important parameters, such as the roll angle at which openings become submerged or at which a minimum level of righting energy is reached.
2. Thank you for supporting our Report.
3. The previous (23rd ITTC) Stability Specialist Committee had reported that all numerical models had problems with predicting the motion behaviour consistently in extremely steep waves. The focus of this Committee’s research was on moderately steep waves, which should be dealt with adequately before moving on to extreme waves. Figure 2.7 of our Report is the outcome for an extreme wave steepness of 1/10 as a follow-up of the 23rd ITTC benchmark testing. If we obtain some missing but important elements from a captive test, we may better predict the ship behaviour up to the point of capsize.
4. The GZ curves of the Ship A-2 are as follows:

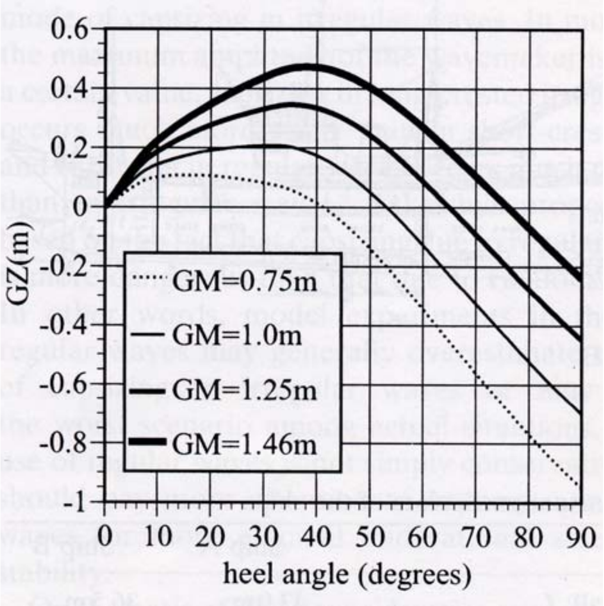

Figure 2.1- The GZ curves of the Ship A-2 in calm water (Umeda et al., 1999).

5. Numerical simulations of the flooding and dynamics of damaged passenger and naval ships have been carried out for ships with hundreds of compartments and multiple openings per compartment. For such computations to be successful, the following is necessary:

- time domain approach with large motion displacements and angles,
- 6 degrees of freedom,
- no assumption of quasi-equilibrium conditions of the ship,
- small time steps, especially for transient flooding scenarios,
- full interaction between any outside openings and inner connected compartments,
- iterative flooding computations with continuity of floodwater mass.

CFD will provide a powerful technique when coupled with a ship dynamics program, but for connected and complex geometries the hydraulic flow model will remain practical in the foreseeable future for predicting the flooding process and resulting ship behaviour. The hydraulic flow model has been validated in this regard through model experiments, as has been reported at the International Stability Workshops and STAB Conferences.

References.

Umeda, N., Matsuda, A., Hamamoto, M. and Suzuki, S., 1999, “Stability Assessment for Intact Ships in the Light of Model Experiments”, Journal of Marine Science of Technology, Vol. 4, pp. 45-57.

2.2 Reply from the 24th ITTC Specialist Committee on Stability in Waves to Marcelo Neves

The effects of the parameters R_0 and R_2 other than R_1 can be important as you pointed out for the accurate prediction of parametric roll magnitude. And, in our opinion, these terms could result from non-linear Froude-Krylov component effects, wave- making and hydrodynamic lift components, which are tasks to be investigated further.

We agree with the need for establishing a benchmark programme on head sea parametric rolling at the next term. This will be addressed by the next Stability in Waves Specialist Committee.